Full investigation

Measuring the speed of sound by setting up longitudinal stationary waves in a column of air

Apparatus

- large measuring cylinder (at least 35 cm tall)
- 5 tuning forks of different frequencies (middle C and above)
- half-metre rule
- rubber bands
- thermometer
- wide glass or plastic tube of length about 50 cm that will go inside the measuring cylinder

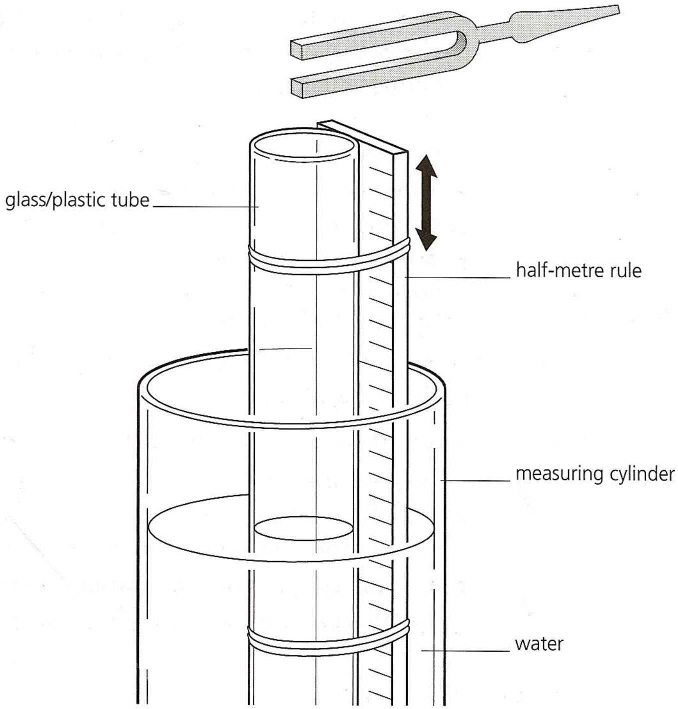

Figure 12.8

Plan

- Fill the measuring cylinder almost to the top with water.
- Use the rubber bands to fix the half-metre rule to the glass tube, with its zero mark exactly at the top end.
- Place the tube and rule in the water in the measuring cylinder.
- Strike the middle C tuning fork on your heel (or on a rubber bung) and hold it horizontally above the mouth of the tube.
- Listen to the note, and raise and lower the tube until the air column resonates – the volume of sound from the vibrating air column reaches a maximum.
- Take the reading of the metre rule at the water level. This is the length of the air column (ℓ). Note the frequency of the fork (f).
- Choose the tuning fork with the next highest frequency, find its resonant length and measure as before. Repeat with all of the tuning forks.
- Measure the temperature of the air in the tube.

Skill level (Implementing)

A: I constructed the apparatus with the end of the tube at ear level. I could strike the tuning fork correctly and make it sound. I was able to find a resonance position. I asked a colleague to help me measure the length of the air column. I found resonant lengths for 4 other forks.

All but one of the above = B; all but two = C; all but three = D; all but four = E.

Analysis

1 Record the readings of length and frequency in a table or a spreadsheet, adding two rows for the calculations of wavelength and speed (see the *Sample readings* below).

Resonance occurs when a stationary wave is formed in the air column. The first resonance occurs when the length of the air column (ℓ) is one quarter of the wavelength of the sound wave (λ). A pressure node forms at the open end of the tube and a pressure antinode at the water surface where the sound is reflected.

$$\lambda = 4\ell$$

2 Calculate the speed of sound ($v = f\lambda$) for each frequency.
3 Calculate an average value for the speed of sound at the temperature of the air in your experiment.

Sample readings

Air temperature = 24 °C

frequency /Hz	256	288	320	384	427	480	
length of air column /cm	33.0	28.9	25.9	21.7	19.8	17.3	
wavelength /cm	132.0	115.6	103.6	86.8	*	*	
speed of sound /m s^{-1}	338	333	332	333	*	*	average *
							std 2.7

Calculate the missing values of wavelength and speed (*).
Calculate the average value of the speed of the sound wave.

Answer $334 \pm 3\ \text{m s}^{-1}$ at 24 °C.

Evaluation

The chief uncertainty is in the resonant length of the air column. The tube has to be positioned by judging when the sound from the vibrating air is a maximum, and then the length measured by the metre rule. There could easily be an uncertainty of 3 mm in positioning the tube and an extra 1 mm in reading the water level on the metre rule.

The overall random uncertainty can be estimated from the numerical difference of each value from the average, or the standard deviation. This is about $3\ \mathrm{m\,s^{-1}}$ ($\sim 1\%$) for the sample readings.

In fact the pressure node of the stationary wave does not occur exactly at the end of the tube but a small distance outside. This introduces an unknown systematic uncertainty – or ‘end error’ – which makes all the readings, and the final result for speed, inaccurate (too small).

Improving the plan

- Eliminate the end error by measuring the distance from the first resonance position ($\frac{1}{4}$ of a wavelength) to the second ($\frac{3}{4}$ of a wavelength). This gives a value for $\frac{1}{2} \times$ wavelength. You will need long tubes to do this.
- Use a microphone and oscilloscope or a sound level meter to determine when the sound level is maximum.